Battlefield Damage Assessment and Repair: Is Improvised Maintenance the Battlefield Solution to the Repair Parts Dilemma?

A Monograph
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ABSTRACT

BATTLEFIELD DAMAGE ASSESSMENT AND REPAIR: IS IMPROVISED MAINTENANCE THE SOLUTION TO THE REPAIR PARTS DILEMMA? by MAJ Judith K. Lemire, USA, 66 pages.

The U.S. Army's repair parts system has experienced continuing problems. Cost and transportability factors limit the amount of stocks we can keep at the unit level. Difficulties in the distribution system compound the resupply problem. Even after a multitude of studies and initiatives to improve supply performance, our Desert Shield/Desert Storm experience confirmed the reality of the continuing repair parts system shortfalls.

This monograph discusses some of the inherent difficulties in the repair parts system, focused primarily on the methodology used to determine repair parts stockage at the unit level and concludes that there may in fact be no ideal solution to this problem. The monograph then suggests that using Battlefield Damage Assessment and Repair (BDAR), relying more on improvised maintenance, could serve to alleviate some of the repair parts shortfalls.

This monograph discusses the U.S. Army's and foreign armies approaches to BDAR and analyzes the potential of BDAR to alleviate repair parts supply difficulties. Finally, it offers recommendations to enhance the U.S. Army's current BDAR program so as to maximize the return of combat systems capability on the future battlefield. These recommendations include an increased training focus and reorientation of our peacetime practices to build a "BDAR mentality" among operators/crews and mechanics and further incorporation of BDAR into the materiel acquisition process. The monograph also includes a proposed methodology to incorporate the BDAR concept into the repair parts stockage determination process.

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I. INTRODUCTION

> The force which is better able than its opponent to recover damaged equipment and return it to service rapidly will have a clear advantage in generating and concentrating combat power. For the force operating at a numerical disadvantage, the capability to maintain, recover, and repair equipment will be even more important.[1]
>
> \- Field Manual 100-5

As a smaller force, relying on high technology weapons and operating on the modern, lethal battlefield, the U.S. Army must rapidly repair damaged vehicles and return them to combat. The Army's maintenance and repair parts systems must be structured to support this end.

The nature of a maintenance system is influenced by weapons system design. The U.S. Army prefers modular type construction of its weapons systems, where individual modules are designed to be replaced at failure rather than repaired at the unit level.[2] Consequently, the maintenance system is highly dependent on the availability of repair parts.

However, the repair parts supply system has proven unable to keep pace with the Army's needs. Cost and transportability factors limit the number of parts a unit can stock. Difficulties in the distribution system compound the resupply problem. Even after a multitude of studies and initiatives to improve supply performance, Desert Shield/Desert Storm experience confirmed the reality of the continuing repair parts system shortfalls.[3]

The U.S. Army Quartermaster School has undertaken yet another study, the Battlefield Spares System (BSS) initiative, to address some of the shortcomings in stockage and distribution policy at the unit and division levels. Unfortunately, many of the same difficulties which plagued earlier attempts at improving repair parts stockage policy are likely to frustrate the recent BSS as well. Predicting component part failures on complex systems has proven to be a difficult, almost impossible task, and continuing budget constraints will further reduce the ability to stock required parts at the unit level.

Battlefield Damage Assessment and Repair (BDAR), an alternative maintenance approach involving quick fixes and other improvisational techniques, may offer some capability to mitigate the shortfalls of the U.S. Army's repair parts system. Historically BDAR has proven effective in restoring combat power to the battlefield in a timely manner. But how much contribution can the U.S. Army expect from BDAR methods given today's complex weapons systems and the modern, lethal battlefield?

To answer this question, this monograph first studies the current maintenance and repair parts systems to establish the existent difficulties. Second, it examines the methodology of recent initiatives and assesses their ability to solve the repair parts dilemma. Next, it addresses BDAR, including historical examples and U.S. and foreign armies' doctrines, and analyzes BDAR as a potential alternative for the battlefield. Finally, it offers recommendations for fully integrating BDAR into the U.S. Army maintenance system.

II. CURRENT MAINTENANCE AND REPAIR PARTS SYSTEMS

The U.S. Army's maintenance system consists of four levels of maintenance: unit, direct support, general support, and depot. Unit level maintenance, performed by operators/crews or unit maintenance personnel, consists of preventive maintenance, services, and diagnosis and replacement of unserviceable parts, modules, and assemblies. Direct support maintenance, performed by maintenance teams/units at the brigade and division level, consists of inspection and repair of unserviceable end items and components. Only unit and direct support maintenance return equipment to the owning unit. General support maintenance, performed by maintenance teams/units at corps and above, and depot level maintenance, performed at fixed facilities in the continental U.S. (CONUS) or at theater level, repair and return components and systems to the supply system.[4] As unit maintenance offers the most timely return of equipment to the battlefield, this study will focus on this level.

In peacetime the level which performs a repair depends on guidance included in the weapons system's technical manual. In general, more extensive repairs are performed at higher levels. During combat, METT-T (mission, enemy situation, terrain, troops available, and time) analysis also contributes to the level of repair decision.[5] Longer repairs usually require further evacuation. A typical timeline allows only 2 hours for an on-site repair, 4-6 hours at a unit maintenance collection point or the battalion trains, 24 hours within the brigade support area, and 36 hours within the division support area.[6] If a repair part is needed, the time required to get the part and transport it to the repair site is included in overall repair time. Therefore, if the part is not readily available, the equipment will probably have to be evacuated. Unit maintenance sections currently stock a limited quantity of repair parts known as the Prescribed Load List (PLL). The PLL should contain sufficient repair parts to sustain the unit in peace or war for a specified number of days. A CONUS-based, active Army unit typically maintains a 15-day supply.[7]

If a unit could stock every repair part it might need during this supply period, it would never suffer from a parts shortage. However, with limited transportation assets available to carry supplies into combat, the number of items in a unit's PLL is limited (by regulation, this limit is 300 different parts, although exceptions can be made, provided the unit is still able to transport its entire stockage).[8] As the number of potential repair parts is great, a PLL must be selective, including only those items which are both most critical to the weapons system and most likely to fail.

Another constraint on unit stockage is funding. The modular design of many weapons systems results in high cost components which are replaceable at the unit level. Stocking these parts greatly increases the funds tied up in unit level inventory. With decreasing budgets, the need to minimize this cost becomes more important.

There are two primary methods for determining PLL stockage. The first, traditional means is demand history. The second, based on an initiative begun in the late 1970's to standardize PLLs across the Army, is the Mandatory Parts List (MPL) or Combat PLL.

When a unit orders an item frequently, that part can be added to the PLL as a demand supported item. However, demand in a peacetime training environment will not necessarily be representative of a wartime operational tempo. The MPL is designed to bridge this gap. The Materiel Readiness Support Activity (MRSA) is responsible for determining the standardized MPL stockage levels.

To produce the MPL, MRSA uses information from a variety of sources. The Army Materiel Command's (AMC) major subordinate commands, e.g., the Tank and Automotive Command and the Communications and Electronics Command, provide MRSA with lists of candidate repair parts. These parts are critical to the operation of the weapons system and replaceable at the unit level. The major subordinate commands also furnish estimated failure rates for each part, i.e., the average number of miles/hours of system operations before the given part will fail. The Army's Training and Doctrine Command (TRADOC) gives MRSA the mission profile for each weapons system, i.e., expected usage during the first 15 days of combat.

MRSA forwards these inputs to the Army Materiel Systems Analysis Activity (AMSAA) Inventory Research Office, to be processed in their

Selected Essential Item Stockage for Availability Method (SESAME) model. Based on systems usage and estimated failure rates, SESAME predicts which parts will fail for a given operational tempo. It then determines the optimal repair parts stockage, by either maximizing availability given a cost limit, or minimizing cost, given an availability requirement.

SESAME has a number of limitations. SESAME addresses only maintenance failures, that is, failures due to usage only and not combat damage. The model also makes the simplifying assumptions that component failures will be statistically independent and that components can be modeled as having constant failure rates, i.e., the likelihood of a part failing is independent of its age.[9] As discussed below, these assumptions may not be valid. The SESAME model's documentation addresses these concerns and offers limited solutions for the situation when component failures are linked (failure in component "A" makes a failure in component "B" more likely) or for simple alternative (other than constant failure rate) failure processes.[10]

Using a methodology similar to the MPL development, MRSA also develops stockage lists for newly fielded end items, where no unit demand history exists. These Support List Allowance Card (SLAC) parts are generated by the SESAME model using engineering failure rate predictions developed as part of the materiel acquisition process. The SLAC parts listing fills the gap between time of fielding and the time at which demand history can support a viable stockage for the new item.

While MPL and SLAC initiatives were designed to standardize and improve upon the Army's repair parts policy, concern still exists as to whether these procedures coupled with the demand support methodology can support a unit in combat. The Quartermaster School estimates that of all the parts a unit requests, the PLL only meets 15 - 20% of them. MPL usage, while slightly greater, is still less than 32%.[11] Clearly, this indicates an unresponsive system in which units carry the wrong parts on critically limited transportation assets.

Operations Desert Shield and Desert Storm offer further evidence of the repair parts system deficiencies. The mismatch of repair parts stockage coupled with the inability of the distribution system to keep up with the high number of demands for repair parts created a situation where exceptional measures to acquire repair parts became routine.[12] One CONUS-based division support command commander called peacetime PLLs "totally inadequate," citing costs and peacetime requirements as constraints.[13] A field artillery brigade estimated that it obtained 80% of its high priority parts through scrounging.[14]

Why is the PLL and its MPL component failing to provide the needed repair parts? Why did the repair parts system fail during Desert Shield/Desert Storm? To answer these questions, one must look closer at the MPL process.

The MPL methodology assumes constant failure rates, i.e., the likelihood of failing being constant throughout the lifetime of a component. Due to their complexity, most models use this simplifying assumption. In reality, however, parts will typically exhibit either increasing or decreasing failure rates. Mechanical parts tend to be more likely to fail with age, while many electrical parts will either be faulty and fail in infancy or be good and last a long time.

The constant failure rate assumption, while not necessarily valid for a single component or weapons system, can be a fair assumption for a fleet of systems providing those systems are at varying ages.[15] However, since new equipment is usually fielded all at once, most units have systems with similar ages. Consequently, the recommended stockage levels may be inappropriate for a specific unit, given the age of its fleet.

Another shortfall of the PLL is that combat damage is never addressed. Demands during peacetime will not reflect the combat environment. The methodology used for both the MPL and SLAC development accounts only for the expected increase in failures due to increased operating tempo in combat, but not the combat damage likely on a lethal battlefield.

III. INITIATIVES TO IMPROVE REPAIR PARTS STOCKAGE

Research to improve stockage selection criteria to consider factors besides demand is not new. Both the civilian and military sectors have been working in this area since the 1960s. During that decade, under Secretary of Defense Robert S. McNamara, operations research (specifically, cost-benefit analysis) became a primary tool for military force planning.[16] Within the last two decades, other initiatives have followed.

The 1981 Defense Science Board recommended the services use reliability theory concepts (a discipline within operations research), whereby system availability rather than demand would be the driving factor for stockage.[17] Reliability theory is basically an approach to increase overall reliability by improving the weak link in a system. In doing a reliability theory analysis, the analyst breaks a system down into subsystems and then further reduces those subsystems to components and subcomponents until the system can be fully defined in terms of its smallest operational parts. Components are either required for system operation (they must all work, as in a series system) or are part of a redundant subsystem (where any one must work, as in a parallel system). To improve reliability during system design, find the least reliable components and either improve them or add redundancy. To develop a repair parts stockage methodology based on reliability theory to improve overall availability, stock those parts which are the most likely to fail and which are the most critical to the system. This is known as sparing to availability.

This shift from the demand based repair parts stockage to the sparing to availability methodology reflected a fundamental change in how the U.S. Army measures repair parts adequacy. In the words of the Deputy Assistant Secretary of Defense for Manpower, Reserve Affairs, and Logistics,

> The traditional approaches to determining levels and measuring supply performance have been related to the satisfaction of demands for items of supply...[We must] Relate stockage decisions to the effect they have on weapon system readiness. This concept represents a significant departure from traditional supply management...[18]

For new systems, the Defense Science Board panel also recommended that the services use computer models to determine cost estimates for the spares necessary to achieve an availability standard. That cost could then be computed into the overall system cost prior to a procurement decision.[19]

Models, however, are only as good as their underlying assumptions. Many studies have investigated the validity of the constant failure rate assumption. Metzner, in looking at U.S. Air Force war readiness spares kits, observed that actual lifetime data exhibited a greater variance (therefore less predictability) than one would expect from components having a constant failure rate.[20] A 1988 study by the RAND Corporation looked specifically at M1 tank electronic components. This study indicated that there were erratic fluctuations in failure rate that would rule out the constant failure rate model and would, in fact, make it difficult for any supply system to be able to respond to failures effectively.[21] RAND's recommendation to the Army was to accept that inventories at the user level could only meet the needs with a large investment in inventories and that a better solution would be to concentrate efforts on improving the transportation and distribution systems.[22]

One recent study suggests that instead of relying on failure rates provided by AMC for use Army-wide, divisions update failure rates and incorporate this information into their internal stockage determination decisions.[23] This would be extremely difficult, in that the Army does not routinely capture the data necessary to do such a calculation. Specifically, this computation requires the operating lifetime of each part at time of failure. While this could potentially be tracked, units do not currently report such use data when they requisition items. Modifying the requisitioning system to include such information would require substantial changes to the large number of automated systems which process this data.

To address combat related failures, AMSAA has developed the Sustainability Predictions for Army Spare Components Requirements for Combat (SPARC) methodology. This model determines combat damage caused by ballistic weapons effects. When SPARC is coupled with the Concepts Analysis Agency's (CAA) threat simulation, an estimate of parts required for repair of non-catastrophically killed weapons systems is possible. So far, these models have not been used for developing repair parts stockages except for a study on war reserve stocks.[24]

For various weapons systems, the SPARC and CAA models identified the 10 most likely parts to require replacement, in both non-combat (reliability failure only) and combat environments.[25] Not too surprisingly, the lists differed substantially. (See tables 1 and 2.) For a tank, all of the top ten reliability failures are in the mobility subsystem (track, suspension, or engine). In contrast, fire control/firepower subsystem components, not likely to fail in routine usage, are high on the combat casualty list. Where estimated failure rates were included, the distinction between the combat and non-combat environments is even more striking. (See tables 1 and 3).

As part of the war reserves study, the same models demonstrated a potentially more significant result. The study estimated that in a theater of war the great majority of failures wiii be combat related.[26] Clearly, developing a repair parts system solely around non-combat failure predictions will be inadequate, especially when a preponderance of the failures will be due to combat damage.

Table 1. Top 10 Repair Parts for the M60A3[27]

Reliability Failures		Combat Damage	
Item	Rate[1]	Item	Rate[2]
Track Shoe, Vehicular	3480	Cdr Laser Rnge Finder	39
Wheel Solid Rubber	384	Track Shoe, Vehicular	32
Track Assembly	212	Main Gun Mt M140A1	30
Sprocket Wheel	58	Turret Power Relay	27
Battery Storage	54	GPFU Heater	27
Bar Torsion	42	Cdr's Periscope M36E1	18
Fan, Centrifugal	33	Gun Fire Relay Box	18
Engine	33	Replenisher	18
Transmission	29	Day V18 Periscope	14
Bar Torsion	29	Turret Race Ring	14

1. Based on Field Exercise Data Collection (FEDC) Report for FY 89; rate is expected number of failures given 100 systems for 60 days.
2. Based on results of CAA/SPARC methodology; rate is expected number of failures for 100 systems in the first 60 days of combat.

Table 2. Top 10 Repair Parts for the AH-1S[28]

Reliability Failures	Combat Damage
Hub Assembly Part	Main Rotor Blade
Servo Cylinder	Window Panel
Hub and Blade Assembly	Panel Assembly Main Beam
Tail Rotor Drive Shaft	Wing Assembly
Scissor and Sleeve Assembly	Engine Gas Turbine
Engine Gas Turbine	Glass Frame
Blase Assembly Main Rotor	Glass Frame
Link Assembly	Tail Rotor Blade Assembly
Tail Rotor Blade Assembly	Tank Assembly Fuel AFT
Mast Assembly	Glass Frame

NOTE: This study did not include failure rates for this system.

Table 3. Failure Factors for Top 10 Combat Damaged M1 Components[29]

Item	Reliability Failure Rate*	Combat Failure Rate*
GPS Body Assembly	16	206
Coax Cable 7059	1	126
Coax Cable 4723	1	126
Special Cable 13061	NA	118
Special Cable 13062	NA	118
Special Cable 13063	NA	118
Coax Cable 7058	1	112
Cable 1W200	9	103
Remote Freq Control	1	102
GPS Cdrs Extension	1	95

* Rates are expected number of failures for 100 tanks for one year.

IV. THE BATTLEFIELD SPARES SYSTEM INITIATIVE

The Quartermaster School is currently working on the Battlefield Spares System (BSS), a redesign of the repair parts system which includes a variety of initiatives within the division. Proposed changes include the on-board spares concept and the absorption of the unit's PLL into its support battalion's repair parts stockage.[30]

By storing those repair parts replaceable by the operator/crew on the weapons system, on-board spares simply serve to reduce the resupply time for those maintenance tasks. On the battlefield this time reduction could mean the difference between repair on-site and evacuation. Current doctrine already allows units to do this; BSS will simply formalize the procedure.[31]

By absorbing unit PLLs into their support battalion's stocks, individual units would no longer manage their own PLLs. Stocks could still be positioned forward, as BSS relies on automated data processing technology to allow the support battalion's stocks to be "split" and distributed around the battlefield. This forward stockage would serve the same purpose as the present PLL. BSS hopes to achieve a reduction in total inventory based on its centralized management.[32]

BSS also includes an effort to develop more useful repair parts stockage lists. To assist them in this effort, the Quartermaster School, like MRSA, has turned to the Army Materiel Systems Analysis Activity (AMSAA) Inventory

Research Office. The study intends to use the same SESAME model with its constant failure rate assumption. Factors to be included in stockage criteria include the probability of failure (based on engineering and field exercise data), combat criticality, time to replace, and transportability.[33]

By using the same model as the MPL process, the BSS initiative is likely to suffer some of the same pitfalls. Like the MPL, this study also suffers from a lack of adequate reliability data: the part's operating lifetime at time of failure is still unknown. Instead of AMC's failure rate estimates, the BSS will use field exercise data such as repair parts usage data from a Combat Training Center (CTC) rotation. BSS will average a constant failure rate (per mission day) for each part, assuming that the field data is based on a representative 15-day mission profile. However, if in those 15 exercise days, the vehicles only operated half as much as they would in the first 15 days of combat, the stockage levels computed by the model will be half that needed to support the unit in combat. BSS also continues to ignore the need to consider combat damage in the computation of stockage levels.

V. ANALYSIS OF THE REPAIR PARTS SITUATION

Even with the myriad of studies over the past 10 years to determine ideal repair parts stockage policies, the solution is still elusive. These studies spanned not only the Army and other military services, but addressed the civilian community as well. Most studies examined a particular type of repair part or single process, for instance electrical components or aviation systems. These studies tried to identify particular idiosyncracies of a family of parts which can be used in a model to predict failures. Unfortunately, the Army has difficulty applying these study recommendations for several reasons.

Weapons systems are so dispersed throughout the Army that data collection for reliability purposes is very difficult. Studies which have attempted to derive specific failure information have typically focused on a single installation or division. The current Army system does not include a mechanism for collecting such data on an Army-wide level. Even in this age of automation, processing inputs for this type of data could be an undue burden on the unit supply personnel.

Couple with this difficulty in data collection the vastness of the Army's repair parts system. There are 132 individual repair parts of the M1A1 tank alone which are critical to the operation of the system and replaceable at the unit level. These parts range from track shoes to spark plugs and from circuit cards to fire control computers.[34] Trying to use a single model to address this variety of items requires the use of assumptions -- the constant failure rate assumption being most common. Compound this with the 1988 RAND study which concluded that some types of parts perform so erratically that it is virtually impossible to predict failures with any accuracy. It is not surprising that the repair parts system so poorly reflects the requirements.

Another difficulty, equally important but rarely addressed, is predicting the future battlefield. While the Concepts Analysis Agency's (CAA) model and TRADOC's mission profiles try to estimate the type of threat and the operational tempo for combat, the problem is reminiscent of Michael Howard's warning on doctrine and the next conflict: it should not be "too badly wrong," and the Army must be able to "get it right quickly."[35]

The Army adapts to being wrong on repair parts stockages with its supply distribution system. During Operations Desert Shield/Desert Storm, the distribution system was one of the key problems.[36] Parts were not delivered in a timely manner. Some units complained of receiving no repair parts and scrounging became routine.[37] Current initiatives, not addressed by this monograph, are looking into applying modern technology to improve the Army's ability to track parts in transit and hopefully reduce the time to deliver critical items. However, in the words of one Desert Storm Corps Support Command commander, "building a maintenance system which relies heavily as does this one, [sic] on supporting transportation is, in my view, ill advised."[38]

Clearly, there is a need to reduce the impact of the repair parts system inadequacies. The use of Battlefield Damage Assessment and Repair (BDAR) maintenance procedures might offer an alternative approach for addressing this dilemma.

VI. BATTLEFIELD DAMAGE ASSESSMENT AND REPAIR

Battlefield Damage Assessment and Repair (BDAR) is a maintenance concept involving improvisation on the battlefield to return a damaged system to some level of combat effectiveness or allow it to self-recover. As BDAR fixes often involve a degradation in system performance and could also have longer term destructive effects, they should be replaced by doctrinal maintenance methods as soon as the combat situation allows."[39]

U.S. ARMY BDAR PROGRAM

BDAR is relatively new to U.S. Army maintenance doctrine, however, as a concept it has probably always existed. In fact, one historical example dates back to the American Civil War, when Sherman's army used tar mixed with flour as a substitute for axle grease.[40]

Today's formal BDAR program began with the first BDAR "how-to" manuals published in 1983. These manuals contained bold-lettered warnings at the start of every chapter stating that BDAR fixes were allowed only when authorized by the commander during combat situations.[41] Given this warning, soldiers were encouraged to view BDAR as the exception, not something essential for sustaining combat power. Also, operator, crews, and mechanics received little to no training on BDAR, either as a concept or through hands-on experience.[42]

Recently, however, the Army has authorized selected, non-destructive BDAR fixes to be applied in peacetime. Updated BDAR manuals are to highlight applicable procedures. The Training and Doctrine Command (TRADOC) BDAR office is also conducting a study to determine the feasibility of incorporating BDAR fixes directly into the operator and maintenance manuals. The hope is that these initiatives will allow more familiarization and some hands-on experience during peacetime, as well as help instill a philosophy of improvisation and ingenuity.[43]

Another aspect of the U.S. Army's BDAR program is participation in Germany's annual live fire BDAR trials in Meppen. During these trials, explosives, such as artillery rounds or tank mines, are detonated in the proximity of actual combat vehicles. Maintenance crews then attempt to repair the damage through use of BDAR techniques.

The primary purpose of the trials is to identify and validate BDAR procedures. The Meppen live fire trials serve a secondary purpose of providing survivability and vulnerability data to update AMSAA's Sustainability Predictions for Army Spare Components Requirements for Combat (SPARC) data base. Due to safety limitations and attempts to limit catastrophic damage in live firings, not all types of combat damage may be represented. For instance, hydraulic systems are not under pressure during firing events.[44]

From a training standpoint, the Meppen trials have proven invaluable. At the start of the trials, maintenance teams drawn from units stationed in

Germany were typically skeptical of their ability to repair significant combat damage. However, as the trials progressed, their confidence increased. As one report states:

> The initial reaction of soldiers exposed to combat damaged equipment is that it can't be repaired. These tests forced them to use their ingenuity and showed that with a little initiative they actually could repair a significant amount of the damage and make most of the equipment operable again.[45]

The high success rate adds to the soldiers' enthusiasm. In the 1987 trials, for instance, 90% of the vehicles were returned to at least a partially operable status. Event reports by both AMSAA and AMC's Tank and Automotive Command cite the value of a training "ripple effect." The authors of these reports believe that soldiers who participated in the trials will be able to pass on their experience to the soldiers in their unit who did not participate.[46]

Another recent initiative is the development of Battle Damage Repair (BDR) kits. Partially based on those procedures developed and validated during the Meppen trials, these kits contain supplies such as wire, electrical tape, clamps, and special patch kits which can be used for jury-rigged fixes. The TRADOC BDAR Office, together with AMC's major subordinate commands, is developing three ground equipment kits: one for the M1, one for the M88A1, and one for the M2/3/generic (all other) equipment/vehicles.[47] The Aviation Systems Command is developing a variety of commodity oriented kits, such as electrical repair and fuel cell repair, to support aviation BDAR.[48]

Even with this recent emphasis, units were limited in performance of BDAR during Operations Desert Shield/Desert Storm. One observer noted that even when BDAR procedures were possible and necessary to keep equipment operational, they were not being done.[49] Some of the possible reasons for this may be gleaned from other lessons learned observations. While provisional BDR kits (the actual kits still under development) were sent to the Persian Gulf in January 1991, many units did not have the kits.[50] [51] Another observation noted the inability of forward support battalions to fabricate small valves and hoses due to the lack of any hydraulic or machine shop capability.[52] One observation suggested a lack of diagnostic equipment and skills and suggested that, "our mechanics need to understand how to repair equipment rather than replace parts."[53]

Since Desert Shield/Desert Storm, efforts are continuing to improve BDAR training. In 3rd Quarter FY91, the Ordnance Center and School increased the BDAR basic noncommissioned officer course (BNCOC) training for military occupational specialty 63B (light wheeled vehicle mechanic, responsible for unit maintenance and recovery operations) from 6 to 14 hours. Only 2-4 hours of the training is conference time; the remainder is hands-on training, focusing on those areas determined most valuable during the Meppen live fire trials and live fire testing conducted by the Ballistics Research Laboratory. The school hopes to expand this training to their other BNCOCs.[54]

The TRADOC BDAR office is planning to use an exportable training package to train units on the use of the BDR kits. Use of the kits will also be incorporated into the BDAR training in the BNCOCs. One Desert Storm lesson learned recommended including BDR kit training in individual soldier advanced individual training (AIT) as well.[55] However, there is no current plan to do so, possibly due to the limited time available for AIT instruction.[56]

BDAR PROGRAMS OF FOREIGN ARMIES

The German Army far exceeds the U.S. Army in its BDAR capability. The Germans relied heavily on such techniques during World War II. Harsh climates in both North Africa and Russia increased the demand for maintenance and repair parts.[57] As the war in Russia progressed and the main effort was shifted away from the North African front, the supply situation there "grew precarious and tank maintenance personnel had to rely mainly on improvisation and cannibalization."[58] By 1942-1943, tank maintenance personnel were forced to improvise on the Russian front as well.[59] There are documented examples of short-tracking tanks and disconnecting transmissions from steering mechanisms to enable recovery.[60]

Perhaps the most significant aspect of the German World War II experience was their approach to training. Recognizing the imperative of making do with the little that was available, the German Army began training enlisted tank mechanics at depot facilities. They would be allowed to use only those tools and parts likely to be available on the battlefield, and

> great emphasis was placed on teaching the trainee to improvise because in the field some essential item or part would often be missing and, if the tank was to be put back into service as quickly as possible, the repairman would have to use expedients.[61]

The Germans seem to have carried that wartime philosophy into their current peacetime methods. The Germans began their Meppen trials in 1981, with U.S. participation not beginning until the 1986 trials.[62] They also currently use BDAR on a daily basis. The German Army uses BDAR not just as an exceptional combat technique but whenever the lack of a repair part precludes standard maintenance. Unlike the U.S. requirement for a commander to authorize the use of BDAR techniques, the German system is more decentralized, with each officer and NCO in a maintenance unit school-trained on BDAR techniques and procedures and able to authorize their use at the lowest level.[63]

The former Soviet Army also experienced the necessity for rapid repair of combat damaged equipment during World War II. One Guards Tank Army estimated that some of its tanks were knocked out 2 or 3 times, but were repaired and returned to fight.[64] In developing new equipment, the Soviet philosophy was to minimize maintenance requirements, because in a high speed war, serious repair work would not be possible.[65] The current Russian doctrine includes light, or "running" repair, done by regimental or divisional mobile workshops or even by the vehicle crew. This repair work includes such procedures as light welding, which is a form of BDAR.[66]

Perhaps the quintessential example of BDAR being integrated into an army's maintenance doctrine is the Israeli Army experience during the 1973 Yom Kippur War. Israeli commanders credited BDAR efforts as being critical to their victory, particularly in the Golan Heights.[67] At the end of the war, one brigade commander, with only 7 of an original 100 tanks remaining, credited the "incredible bravery and ingenuity of his ordnance unit" for those critical assets.[68] One commander stated that "nearly every Israeli tank was hit during the war, but most of them were repaired - the majority in the course of the fighting."[69] This same commander commented on the "considerable improvisation" occurring at his maintenance checkpoints.[70] Post-war estimates state that 80% of the Israeli tanks were damaged in the first 18 hours, with 75% of those returning to combat within the next 24 hours.[71] This Israeli experience is acknowledged by many as being the source of the U.S. Army's recent interest in this maintenance concept.[72]

VII. ANALYSIS OF BDAR: ITS POTENTIAL CONTRIBUTION TO READINESS

Historically, BDAR is a proven combat multiplier. The Israeli experience in the 1973 Yom Kippur War and the German experience in World War II attest to the ability of maintainers to return systems to combat when commanders are able to accept less than complete "doctrinal" repairs. But can it take the place of the current U.S. Army maintenance concept? How does BDAR measure up in terms of operational availability on the battlefield, feasibility given today's complex weapons systems, and the impact on the cost of repair part stocks?

OPERATIONAL AVAILABILITY

One measure of a maintenance concept is how well it maintains the operational availability (A_o) of a system, that is the proportion of time that a system is either operating or capable of operating.[73] To calculate this measure:

$$A_o = \frac{up\ time}{up\ time + down\ time}$$

Down time includes administrative and logistical down time, for example the time required to order and receive a repair part through the supply system.

The definition of operational availability assumes that there are no in-between states, where a system may be "somewhat" capable. Yet, with BDAR a system may be brought to varying degrees of capability, ranging from fully operationally ready, to degraded yet combat capable, to self-recoverable only. To reflect this possibility, it is useful to define the term "combat operational availability," as the operational availability modified by the percent of performance. Numerically this looks like:

$$CA_o = \frac{\sum_{time=0}^{msn\ completion} (up\ time) \times (\%\ capability)}{\sum_{time=0}^{msn\ completion} (up\ time + down\ time)}$$

Under the standard maintenance concept, operational availability and combat operational availability will always be the same. However, an appropriate BDAR policy can improve upon the combat operational availability.

If both a BDAR and standard fix are possible, and the BDAR fix takes less time and has no limitations, the BDAR procedure gives a reduction in down time and therefore an overall increase in CA_o. If both fixes are possible, but the BDAR fix reduces system capability, the fix which provides the greater CA_o is based on the METT-T factors: how soon is the vehicle needed, for how long will it be needed, how critical is this vehicle to the accomplishment of the near-term mission (before a standard fix can be done), and how long until a standard repair can be made? For example, if it will take 1 hour to restore the weapons system to 80% capability or 6 hours for a full repair and the current battle will last for 10 more hours, after which time full maintenance can be done, the expected A_o and CA_o are calculated as follows:

$$A_o = \frac{\text{10 hours remaining - 6 hours for standard repair}}{\text{10 hours}} = 40\%$$

$$CA_o = \frac{\text{(10 hours remaining - 1 hour for BDAR repair) (80\%)}}{\text{10 hours}} = 72\%$$

The calculation of CA_o, however, is not always as simple as this example. In actuality, the percent capability is mission dependent. For instance, many of the BDAR procedures for the track and suspension system of the M1 tank come with the limitation of reduced mobility and steering capability. This may be next to no limitation for a static defensive mission however, it may be a great limitation for an offensive maneuver mission. In the latter case, the degradation may be so great that the BDAR fix should not be considered. In the above example, one can solve for the "break-even" point, i.e., that percent capability below which the standard maintenance fix would be preferable:

Equating A_o and CA_o, using x to represent the break-even BDAR capability may be represented by the equation:

$$A_o = 40\% = \frac{(10\ hours - 1\ hour)\ (x\%)}{10\ hours} = CA_o$$

Solving for x:

$$x = 44\%$$

In this case, if the combat capability of the BDAR fix is greater than 44% of the system's full capability, the BDAR fix will provide more overall combat power.

The longer a BDAR procedure takes to perform and the longer the battle is likely to continue, the less worthwhile the BDAR fix. The longer it would take to effect a standard repair (to include time to acquire the necessary repair parts), the shorter the remainder of the battle, and the less the limitation of the BDAR fix, the more worthwhile the BDAR fix becomes. The sample tradeoff curves in figures 1 through 3 demonstrate some of these relationships.

Figure 1 graphically represents the example above, looking at the tradeoff between the BDAR and standard repair varying the percent capability of the BDAR repair. While the A_o for the standard repair remains a constant 40%, the BDAR fix ranges from 0% (with no capability following the BDAR repair) to 90% (full capability repair performed within 1 hour of breakdown).

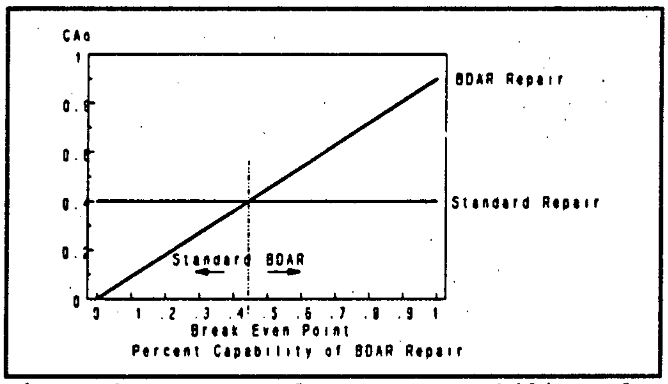

Figure 1. Impact of Percent Capability of BDAR Repair on BDAR/Standard Repair Trade-off

Figure 2 displays the impact of the time remaining in a given mission on the relative value of a BDAR versus a standard repair. For a short duration mission, maximizing immediate combat power through a reduced capability BDAR repair is optimal. For a longer mission, the standard repair might provide a greater overall capability. In the figure below, a 60% BDAR repair takes 1 hour and a standard, 100% repair, 3 hours to complete. For a battle lasting between 1 and 3 hours (when only the BDAR repair is possible) this quick return of combat power yields a higher CA_o than the unfeasible standard repair. Once the standard repair can be made, however, the 100% contribution versus the 60% contribution of the BDAR repair soon provides the greater overall availability fcr the mission.

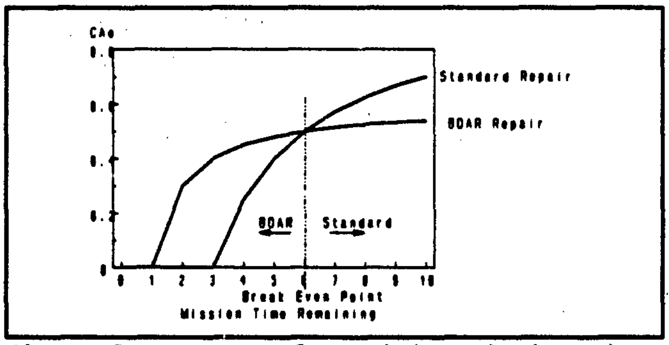

Figure 2. Impact of Remaining Mission Time on BDAR/Standard Repair Trade-off

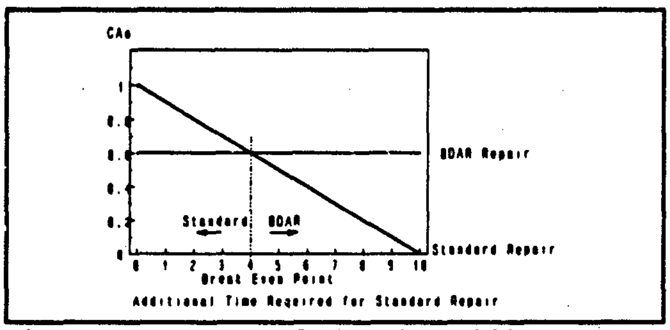

Figure 3. Impact of the Time Difference Between the BDAR and Standard Repair

Figure 3 addresses the relative time involved to execute a BDAR repair. For a standard repair which takes no longer than a BDAR repair, the standard repair will be better. As the length of time to effect the standard repair increases, the immediacy of the BDAR repair yields greater combat availability. In this example, 10 hours of mission time remain following the accomplishment of a 60% BDAR repair. For this repair, the CA_o for the remaining mission hours is 60%. For a standard repair completed at the same time as the BDAR repair, the overall availability for the remainder of the battle is 100%. However, as the down time before standard repair completion increases, the availability decreases, until the repair can no longer be completed within the remaining mission time.

If a standard maintenance procedure is not possible due to a lack of repair parts, the BDAR fix may be the only alternative for returning the system to combat. In this case, any capability, even limited, will be better than no capability. Even if a vehicle is only capable of self recovery, this frees recovery assets to deal with more severely damaged equipment, returns the damaged item to the maintenance point quicker than waiting for a recovery asset, and may enable recovery in a situation where otherwise the system would be overrun by enemy forces.

BDAR FEASIBILITY GIVEN TODAY'S COMPLEX WEAPONS SYSTEMS

In designing weapons systems, current guidance is to use modular components which, upon failure, are replaced rather than repaired.[74] This "black box" approach detracts from the ability to jury-rig or improvise solutions. Even seemingly minor failures (such as an electrical short) may not be reparable at the unit level if the broken wire is within a sealed "black box" or circuit card on which the mechanic has had no training. However, if the crew/mechanic knew which cards/subsystems could be circumvented, the system could at least be returned to limited operation.

An example of this type of procedure is the fire control computer on the

M60A3 or M1 tank. At the unit level this item is replaced vice repaired. System redundancy allows for manual inputs to the computer, but there is no BDAR procedure to address a failed computer.[75] During the Meppen Live Fire Trials of 1987, a ballistic computer suffered damage and was bypassed, reducing the tank's capability to a partially capable status.[76] The tank could still shoot and maneuver, but the reliability of its hits was somewhat degraded (the amount of degradation would depend on the types of shots the crew was making and the skill of the crew itself). Therefore, while BDAR fixes of modules might not always be possible, techniques for bypassing such components will enable soldiers to use BDAR on complex systems.

IMPACT OF BDAR ON THE COST OF REPAIR PARTS STOCKAGE

Many BDAR fixes allow for repair vice replacement of parts. For example, splicing a wiring harness requires electrical tape as opposed to a new harness. Short tracking a tank removes damaged parts without replacing them. These fixes allow for faster return to the battlefield, sometimes because the procedure itself is quicker than the full maintenance action but often because repair parts are not immediately available. Taking the wiring harness for example, a full replacement could be time intensive, especially if to access connections the mechanic must disassemble other components. But splicing could also take time, especially in a large harness and if the wires are not clearly marked. However, if a new harness is not available in the unit, the administrative time alone to get the part (even if it is available in the support battalion stocks) will likely exceed the repair timelines for on-site or even battalion trains locations.

Currently, the Army does not consider the BDAR option when determining repair parts stockages. Stockage criteria allow for the addition of BDAR specific items (such as electrical tape) which are now being supplied with newly fielded BDAR kits. However, if BDAR were considered as a primary maintenance technique, the types of repair parts stocked might be different. More emphasis would be placed on stocking those critical items which lack a BDAR alternative.

An example is the blasting machine for the M1 tank. This item is designed to provide the electronic impulse necessary to fire the main gun in case of loss of vehicle electrical power. Currently, the Mandatory Parts List (MPL) for the M1 tank includes this item. The maintenance time required for unit maintenance personnel to replace a faulty blasting machine is 30 minutes plus the administrative time required to either recover the vehicle to a maintenance collection point or to bring the replacement part forward to the vehicle; the gunner can "hot-wire" the gun firing mechanism in accordance with the BDAR fix in only 15 minutes.[77] Since the blasting machine is a backup system to start with, full repair of the tank may involve more than simply replacing the blasting machine, possibly at a higher level of maintenance. The BDAR fix allows for the same capability as replacement of the blasting machine, therefore having a spare blasting machine at the unit level will not significantly enhance overall combat readiness for that unit.

Wiring harnesses are another example. Splicing a cut harness returns a system to full capability. Depending on the location of the spare harness, the amount of damage, and the difficulty of replacing the harness, splicing might be the quicker alternative.

By accepting some BDAR procedures as routine fixes, the cost of repair parts inventories can be reduced without reducing readiness. In the two examples above, units would no longer have to stock wiring harnesses or blasting machines. The current M1 MPL includes 7 different wiring harnesses and the blasting machine for a total cost of $6463.[78] Other BDAR procedures could most likely yield similar savings.

VIII: RECOMMENDATIONS

Given the potential value of BDAR as a means to mitigate the shortcomings of the U.S. Army's repair parts intensive maintenance system, it is critical that the Army maximize this opportunity through its doctrine, materiel, organization, training, and leadership. The recommendations which follow offer some possible approaches to preparing in peacetime for the realities of a wartime environment.

DOCTRINE

Current maintenance doctrine treats BDAR as an exception. While recent changes have been made to allow some non-destructive procedures to be used during peacetime, the overall message remains that BDAR is a concept designed for combat only. The following initiatives would send a clearer signal regarding the importance of BDAR as the primary maintenance concept in combat.

1. Incorporate BDAR procedures directly into operator and maintainer manuals. This would serve two purposes. First, it would enhance crew and maintenance personnel familiarity with the BDAR fixes. It would allow these individuals to view the BDAR approach along with the standard maintenance approach which would give them a better understanding of the concept of BDAR and the potential performance tradeoffs involved in a given repair procedure. Second, it would present the concept of BDAR in the "routine" manual, as opposed to its current appearance in a special, separate manual. The TRADOC BDAR Office is currently investigating the feasibility of this action.

2. Allow all BDAR procedures (unless destructive) to be performed during peacetime maintenance. While this may sound similar to our current policy, this restated policy makes BDAR the rule, not the exception. It would also encourage soldiers to enhance peacetime readiness through initiative and improvisation. This procedure is currently in practice in the German Army.

3. Consider BDAR as a maintenance alternative when selecting repair

parts for stockage. The current initiatives incorporating reliability theory into repair parts selection are a positive step to support training and readiness in peacetime and therefore should not be stopped. These initiatives will reduce costs of stockage (necessary with today's budget cuts) and maximize the opportunity for standard maintenance repairs. However, along with this, the Army must also relook its wartime criteria. Given that a higher proportion of vehicles will suffer combat damage than maintenance failure, it is reasonable to focus repair parts stockage efforts in that direction. In certain cases, some cost savings may be achieved through the adjustment of repair parts stockage to allow for the full use of BDAR fixes, however, this must be done carefully so as to minimize the risk of decreasing peacetime readiness. A proposed methodology for incorporating BDAR into the repair parts stockage determination process using currently available reliability models is included at Appendix A.

MATERIEL

There are two major issues pertaining to materiel. The first involves the development of weapons systems and the second the development of BDAR technology.

1. Develop and enforce standards of design reflecting BDAR feasibility and procedures. Right now there are few standards for insuring ease of BDAR in new systems. AMSAA has published some suggested guidelines, and some

current Army programs such as the Light Helicopter Experimental program have incorporated BDAR requirements into their materiel acquisition process. However, traditionally BDAR measures have been traded off with such items as cost and system reliability. Given the expected high lethality battlefield with a preponderance of combat damage vice maintenance failures, increasing reliability buys us little in overall combat availability.

More effort needs to be placed on survivability and ease of BDAR. Given a design, emphasis needs to be given to enhancing BDAR capability through such initiatives as marking wires (for ease of repair) and providing BDAR alternatives for non-repairable modular components.[79]

2. Develop BDAR technology to match new technologies being fielded. One example is composite materials, now being incorporated into new helicopters. An acceptable BDAR procedure to patch these items would greatly enhance all affected systems' combat availability. Current regulation requires the materiel developer to ensure BDAR concepts are incorporated into new systems (end item oriented), but tasks no one agency with researching techniques which would enhance capability to do BDAR fixes on specific technologies (commodity oriented).[80] Live fire testing trials assist in this effort, but with new technologies, more effort must be put into a separate research and development initiative.[81]

TRAINING

Based on the comments from the Meppen trials and recommendations from the soldiers of Desert Shield/Desert Storm, enhancing our training in BDAR can assist in developing within our soldiers the expertise and confidence needed to quickly initiate improvised solutions on the battlefield.

1. Continue to expand BDAR training in the basic noncommissioned officer courses (BNCOC). Include some familiarization and hands-on training in advanced individual training (AIT) courses for both mechanics and crew members. Provide some realism in training through use of live fire damaged equipment (as opposed to simply training on BDAR techniques). This will provide a glimpse of the "Meppen experience" to all soldiers expected to perform BDAR. While training time in both AIT and BNCOC is at a premium, we must expand the knowledge of this critical concept if we expect to use it on the battlefield.

2. Provide specialized training on overall system function and capabilities specially geared to understanding the BDAR tradeoffs in performance. This training should be required of all maintenance technicians (warrant officers) and should supplement diagnostic training currently taught in BNCOC. It would be of special value to direct support maintenance support team chiefs and inspectors. This training would be similar to the German Army's advanced maintenance training conducted at their depots during World War II.

3. Incorporate BDAR into unit training through inclusion of BDAR tasks in the Army Training and Evaluation Program. Also, a unit's ability to perform BDAR should be evaluated during CTC rotations.

4. Include BDAR procedures in both the combat vehicle operator/crew and the mechanic's military qualifications standards test. This will reinforce the message that responsibility to take the initiative in improvising maintenance solutions rests with the individual crew member and/or mechanic.

ORGANIZATION

1. Personnel/Force Structure. While some studies recommend special teams for BDAR, this could actually have a negative impact by further removing the sense of responsibility for maintenance from the individual crew.[82] The current organization, with additional training and indoctrination, should be capable of conducting BDAR. Further study should continue, however, on the ability to place more substantial repair capabilities forward within a theater of operations. The concept of such forward repair facilities proved valuable to the Soviets in World War II.[83] For a longer conflict, these capabilities will be essential to repair items receiving significant combat damage and return them to the supply system.[84]

2. Equipment/Resourcing Current Force Structure. Maintenance elements need to be capable of performing likely BDAR fixes. Enhancing capabilities can be done through upgrading unit equipment. One specific

example is the inclusion of hydraulic hose fabrication capability at the forward support battalion level. The TRADOC BDAR Office highlighted hydraulics repair as an area of emphasis based on live fire testing, and the Desert Storm lessons learned also raised the lack of such capability as an issue.[85]

LEADERSHIP

As the element providing cohesi... .o any Army policy/program, enlightened leadership will be the key for a successful BDAR program. All leaders, to include those in combat, combat support, and combat service support roles must be indoctrinated to encourage and accept the initiative and improvisation which are necessary components of this maintenance concept. The individual soldier must be made to sense his own responsibility for keeping his equipment operational.

IX: CONCLUSION

The U.S. Army is currently at a crossroads in logistical support. As our logistics "tail" grows ever larger, the Army can decide to continue to groom it under our current maintenance concept, or the Army could make a major shift and accept that the tail has gotten too long and needs to be trimmed. As S.L.A. Marshall charges in The Soldier's Load and the Mobility of a Nation, in efforts to supply soldiers for every possible contingency, the Army has overburdened our logistics system until it can no longer provide the most essential items.[86]

It's time to accept the reality that the supply and transportation systems can not keep pace with the increasing complexity and technology of today's weapons systems. Once the Army accepts that it will be operating from a position of limited resources (specifically repair parts), it must indoctrinate an improvisational mentality which will allow it, like the Germans in World War II and the Israelis in 1973, to maintain combat strength. Such indoctrination will require more training (especially for mechanics and maintenance technicians) and will require a major change in how the Army does peacetime business to fully inculcate a BDAR mentality. Once achieved, however, BDAR can be an effective tool for the Army to lessen the impact of the repair parts dilemma.

APPENDIX A

A METHODOLOGY FOR INCORPORATING BATTLEFIELD DAMAGE ASSESSMENT AND REPAIR INTO THE REPAIR PARTS STOCKAGE DETERMINATION PROCESS

The following is a suggested reliability theory approach to incorporate the Battlefield Damage Assessment and Repair (BDAR) maintenance concept into the repair parts stockage determination process. The models and simulations addressed in this appendix currently perform functions similar to those described but may require minor adjustments to accept this new methodology.

1. Development of a fault tree diagram for system. A fault tree breaks a system into its functional components, and then breaks each of those down further into its basic essential elements. For a combat system such as a tank, the functional components would be mobility, fire power, and communications (corresponding to the combat functions, move, shoot, and communicate). Each of the components is identified as either a serial (essential for operation, indicated by an "AND" gate) or parallel (one of a number, any one of which is essential for operation, indicated by an "OR" gate) component. For example, the tank engine is essential for mobility, therefore it is a serial component. A track shoe, however, is a parallel component, as only a subset of the total track shoes on a tank must be serviceable for the tank to function. A partial fault tree is given at figure A-1.

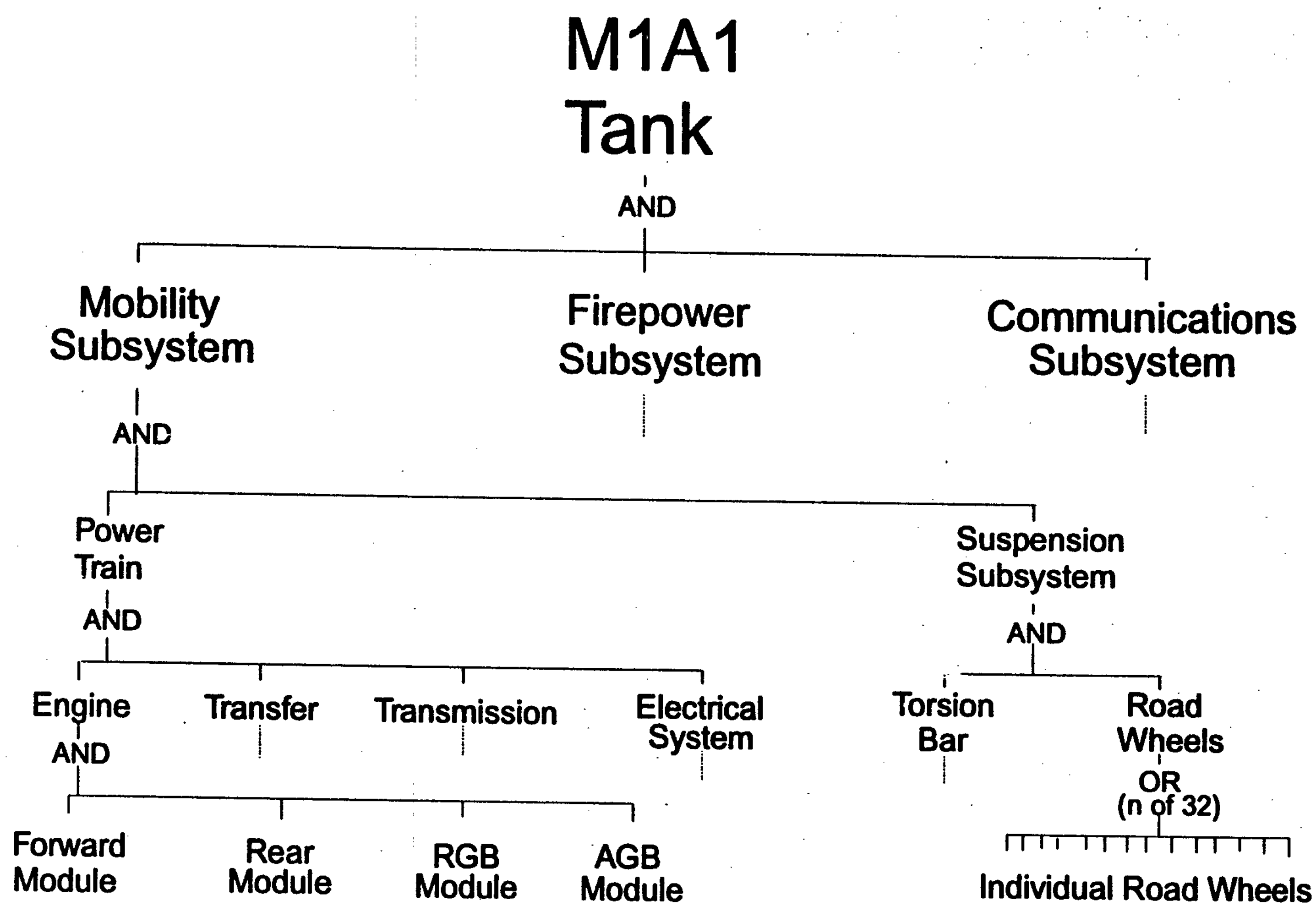

Figure A-1. Simplified, Partial Fault Tree, M1A1 Tank

2. Determine failure rates (engineering estimates or actual field data, if available) and likelihood of combat damage. One possible source is the field exercise data maintained within the Logistics Information File (LIF) system. This data is derived from major field exercises such as National Training Center (NTC) rotations. As the vehicle usage during these periods approximates expected combat mission profiles, this data should be good estimators of expected failure data (for non-combat or engineering type failures).

It should be noted that failure rates can be age dependent (some components, such as mechanical items, are more likely to fail with age; some, like electrical items, are less likely to fail with age; others, display the memoryless property, that is their likelihood of failure remains constant over their lifetime). However, it is unlikely that the demand data will be identified by the age of the item being replaced or even of the vehicle for which it is required. Additionally, the models currently in use assume constant failure rates.

For combat damage, the best source is the Concepts Analysis Agency (CAA) model coupled with the U.S. Army's Materiel Systems Analysis Activity's (AMSAA) Sustainability Predictions for Army Spare Components Requirements for Combat (SPARC) study. The CAA model will also give a ratio of reliability failures to combat damage failures. The overall failure rates should incorporate both types of failures in proportion to this ratio.

3. Calculate initial system reliability. Overall reliability is determined

by combining all components' failure rates in accordance with their relationship to each other (series or parallel). For series components, the reliability is the product of the reliabilities of the individual components, i.e.

$$p_{system} = (p_1)(p_2)(p_3)\ldots$$

For a parallel system, only one component of multiple components must function, therefore the probability of the system functioning is one less the probability of all components failing, i.e.

$$p_{system} = 1 - (1 - p_1)(1 - p_2)(1 - p_3)\ldots$$

4. Identify those subcomponents for which a BDAR fix is possible. Determine the percent capability (or percent of expected performance degradation) of each BDAR fix vs. a standard repair. Degraded gunnery standards offer some data for this effort. BDAR and other technical manuals may also reflect some estimates of degraded levels of performance (for instance, limits on speeds to be traveled on a short tracked vehicle). In some instances, the amount of degradation is mission dependent (in a stationary role, a mobility failure is less significant than in a mobile role). For these cases, estimates of degradation may be made by "subject matter experts," i.e. experienced equipment operators and commanders.

5. Recompute system reliability allowing for a BDAR fix. To do this, increase the p_{system} by the probability of the BDAR repairable part failing multiplied by the percent capability of the BDAR repair, i.e.

$$p'_{system} = p_{system} + (1 - p_1)(p_2)(p_3)\ldots(q_1)$$

where q_1 represents the degraded capability of a BDAR fix to component 1. As degradation levels will vary with mission, reliability for each mission must be computed separately.

6. Use these adjusted reliability estimates in conjunction with AMSAA's Selected Essential Item Stockage for Availability Method (SESAME) model or a similar sparing- to-availability model. Additional inputs required for each component include the time required for each BDAR and standard repair and the cost of the repair parts required. The mission profile associated with each set of adjusted estimates must also be included. The model can then determine the marginal increase in system availability resulting from the availability of each spare component. It can then either minimize cost of the repair parts stockage given a minimum required availability or the model can maximize availability given a ceiling on the cost of the repair parts stockage.

7. Modifications to the above methodology could include a determination of spares available for cannibalization given the maintenance failure and combat damage profiles resulting in step 2. These spares would then be considered on-hand, and a system would have to suffer multiple failures of that part before a degradation in performance. The final model input, however, must consider the maintenance time both to remove and install the cannibalized part.

APPENDIX B

ABBREVIATIONS

AIT	Advanced Individual Training
AMC	U.S. Army Materiel Command
AMSAA	U.S. Army Materiel Systems Analysis Activity
A_o	Operational Availability
BDAR	Battlefield Damage Assessment and Repair or Battle Damage Assessment and Repair
BDR	Battle Damage Repair
BNCOC	Basic Noncommissioned Officers Course
BSS	Battlefield Spares System
CAA	Concepts Analysis Agency
CA_o	Combat Operational Availability
CONUS	Continental U.S.
CTC	Combat Training Center
LIF	Logistics Information File
METT-T	Mission, Enemy situation, Terrain, Troops available, and Time
MPL	Mandatory Parts List
MRSA	Materiel Readiness Support Activity
NTC	National Training Center
PLL	Prescribed Load List
SESAME	Selected Essential Item Stockage for Availability Method

SLAC	Support List Allowance Card
SPARC	Sustainability Predictions for Army Spare Components Requirements for Combat
TRADOC	U.S. Army Training and Doctrine Command

ENDNOTES

1. U.S. Army, Field Manual 100-5, Operations, (Washington, D.C., 1986), p. 61.

2. U.S.Army, Army Regulation 750-1, Army Materiel Maintenance Policy and Retail Maintenance Operations, (Washington, D.C., September 1991), p. 9.

3. This topic is discussed in greater detail in the main body of the paper. For further documentation, see Endnote 12, below.

4. U.S.Army, AR 750-1, pp. 11-13.

5. Ibid., p. 14.

6. U.S. Army, Field Manual 63-2-2, Combat Service Support Operations: Armored, Mechanized, & Motorized Divisions, (Washington, D.C., October 1985), p. 6-3.

7. U.S. Army, Department of the Army Pamphlet 710-2-1, Using Unit Supply System Manual Procedures, (Washington, D.C., January 1992), p. 107; and U.S. Army, Unit Supply Update, Consolidated Glossary, (Washington, D.C., January 1992), p. 9. The number of days of supply is usually dictated by the units major Army command, e.g., Forces Command. It is based on the Average Customer Wait Time (ACWT) which represents the average time between when a part is ordered and when it is received. The 15 days of supply is based on the author's experience.

8. U.S. Army, DA Pam 710-2-1, p. 107.

9. Cohen, Martin; Kotkin, Meyer; and Kruse, Karl, Combat Authorized Stock Lists (ASL), (Aberdeen Proving Ground, MD, 1990) p. 33; and Kaplan, Alan J., Mathematics for SESAME Model, (Philadelphia, 1980) p. 5-8.

10. Kaplan, Mathematics for SESAME Model, pp. 39-40.

11. U.S. Army Quartermaster School, Repair Parts System Redesign, Briefing (Fort Lee, VA, 1991).

12. Many comments from Desert Shield/Desert Storm participants and observers documented at the Center for Army Lessons Learned support this claim. Some specific examples follow:

JULLS DSSN 12 2026: An armored task force processed 5300 requisitions between 1 Jan - 7 Mar 91, with less than 10% being filled. The report states that, "Battalion maintenance personnel had to work around the supply system in order to obtain deadline parts and major assemblies in a timely manner."

JULLS DSTA 7 2703: Referring to combat PLLs and unit maintenance in an armored cavalry regiment: "Class IX repair parts availability for these vehicles was awful. Absolutely unacceptable for an army at war."

JULLS DSST 123 3977: Reference aviation repair parts, this observation states that the supply system was broken, with parts from CONUS not getting to the user. Users had to scrounge parts, and use the "good 'ole [sic] boy" network.

JULLS DSST 83 6500: Reference communications repair parts, "What you bring is all you got! Barter system in place."

13. JULLS DSOP 65 0616, Memorandum, Subject: After Action Comments, Operation DESERT STORM, 10 Mar 91.

14. JULLS DSSN 12 2223,___ Brigade Desert Storm AAR Packet, fig 9, p. 27.

15. Erickson, Richard F., and Hammond, Donald H., Description of Expected Failure Rates of Newly Acquired Components Prior to Steady State, (Wright-Patterson AFB, OH, 1974), p. 18.

16. Weigley, Russell F., The American Way of War, (Bloomington, IN, 1973) pp. 446-447.

17. Under Secretary of Defense (Research and Engineering), Report of the Defense Science Board 1981 Study Panel on Operational Readiness with High Performance Systems, (Washington, D.C., 1982), p. 10.

18. Deputy Assistant Secretary of Defense Juliano, memorandum, 10 March 1982, as quoted in U.S. Army Quartermaster School Briefing, Battlefield Spares System, undated, single briefing slide included in an information package from the Quartermaster School, 11 March 1992.

19. Under Secretary of Defense (Research and Engineering), Report of the Defense Science Board 1981 Study Panel on Operational Readiness with High Performance Systems, pp. 6-13, 6-15.

20. Metzner, H.E., Empirical Determination of War Readiness Spares Component Failure Distribution, (Wright-Patterson AFB, OH, 1982).

21. Berman, Morton B.; McIver, Douglas W.; Robbins, Marc L.; and Schank, John F., Evaluating the Combat Payoff of Alternative Logistics Structures for High Technology Subsystems, (Santa Monica, CA, 1988).

22. Ibid.

23. Takemoto, Glenn H., Management of Repair Parts in the Heavy Division: Is There A Better Way?, (Fort Leavenworth, KS, 1991). pp. 34-37.

24. Kotkin, Meyer. Incorporating Combat Damage Requirements into Combat ASL, (Philadelphia, 1988); Steiner, Kenneth L., Combat Damage Requirements fo. Repair Parts in the Korean Theater, (Aberdeen Proving Ground, MD, 1989); and Srull, Donald W.; Simms, Edward D., Jr.; Schaible, Raymond A., Battle Damage Repair of Tactical Weapons Systems: An Assessment, (Bethesda, MD, 1989), p. ix. The SPARC methodology does not include damage from secondary effects, such as blast overpressure or secondary explosions of on-board fuel or ammunition.

25. Steiner, Combat Damage Requirements for Repair Parts in the Korean Theater, pp. 8, 11.

26. Ibid., p. 1.

27. Ibid., pp. 8, 11.

28. AMSAA Interim Note No. C-97, Sep 1980, p. 75, reprinted in Schaible, Battle Damage Repair of Tactical Weapons Systems: An Assessment, p. B-26.

29. Schaible, Battle Damage Repair of Tactical Weapons Systems: An Assessment, p. B-25.

30. U.S. Army Quartermaster School, Battlefield Spares System, (Draft Concept), (Fort Lee, VA, 6 Aug 91), p. 5-6; Battlefield Spares System-Interim, (Draft Operational Concept), (Fort Lee, VA, 1 Mar 92), pp. 8-10. In the interim concept, a limited amount of repair parts, to be called the Prescribed Parts List (PPL) will be authorized at the battalion level, but the primary source for parts at the unit level will be the Forward Support Battalion (FSB), Division, or Corps ASL.

31. U.S. Army, DA Pam 710-2-1, p. 107.

32. U.S. Army Quartermaster School, Battlefield Spares System, (Draft Concept), p. 5-7.

33. Ibid., p. 9.

34. Candidate Item File (CIF) for the M1A1, provided to the author by MRSA, 26 Feb 92.

35. Howard, Michael, "Military Science in an Age of Peace," RUSI, Journal of the Royal United Services Institute for Defence Studies 119 (March 1974), pp. 3-9. Reprinted in Introduction to Military Theory, Syllabus/Book of Readings for Course C600, Combat Studies Institute, U.S. Army Command and General Staff College, (Fort Leavenworth, KS, July 1991), p. 237.

36. LTG Pagonis, ARCENT Deputy Commanding General for Logistics and Commander 22nd Support Command, stated that "distribution is broken." JULLS DSST 8 3414, Enclosure 3 (Some Thoughts of LTG Pagonis).

37. A multitude of observations from the Desert Shield/Desert Storm lessons learned, collected by the Center for Army Lessons Learned support this point. Some references on order-ship time include:

JULLS DSOP 63 0576: unit parts ordered "months ago;"

JULLS DSOP 63 0580: Class IX turnaround time of "several weeks".

Some specific references about scrounging include:

JULLS DSST 123 3977: Reference aviation repair parts, users had to scrounge parts, and use the "good 'ole [sic] boy" network;

JULLS DSSN 12 2026: "Battalion maintenance personnel had to work around the supply system in order to obtain deadline parts and major assemblies in a timely manner;" JULLS DSST 83 6500: Reference communications repair parts, "What you bring is all you got! Barter system in place;"

JULLS DSSN 1 1896: Credits high operational readiness rate for the Abrams to the ability of maneuver commanders to overcome the problems of non-availability of repair parts through "[scrounging] and cannibalization."

38. McFarlin, Robert P., Memorandum, Subject: Battlefield Maintenance System, TRADOC Pam 525-XXX, AETS-SC-CG (2nd COSCOM), Memo for BG Wilson, 24 Feb 91, DA, HQ 2nd COSCOM, APO, NY 09754., p. 2, para 3.

39. U.S. Army, AR 750-1, p. 26

40. Hagerman, Edward, The American Civil War and the Origins of Modern Warfare (Bloomington, IN, 1988), p. 287.

41. U.S. Army, Technical Manual 9-2350-276-BD, Battlefield Damage Assessment and Repair for Combat Vehicles, (Washington, D.C., February 1984), p. 1-1.

42. Based on the author's experience, no unit training like new equipment training was conducted in the field when these procedures were first published. Per the author's conversation with personnel in the BDAR office at the Ordnance School and a Fact Sheet provided by the TRADOC BDAR Office,

prior to 1991, training for mechanics in BNCOCs at the Ordnance Center and School was limited to approximately 2 hours of classroom familiarization until 1991, when additional hands-on training began to be implemented.

43. TRADOC BDAR Office, (MAJ William Mecum, Mr. Hoy), Fact Sheet, 20 Feb 92; Srull, Donald W., et.al., Battle Damage Repair of Tactical Weapons Systems: An Assessment, pp. 16-17; and U.S. Army, AR 750-1, p. 26.

44. Kruse, Loren; Winter, Leonard; Thompson, Ronald; Mason, Jimmy; and Astor, Raymond, Results of the Meppen BDAR (Battle Damage Assessment and Repair) Firing Trials: Results of the Jointly Sponsored US/FRG Exercise Conducted at Meppen, Germany Test Facility from 14 April to 7 May 1986, (Aberdeen Proving Ground, MD, 1987), p. viii; Berkowitz, David and Kruse, Loren, Results of the International BDAR (Battle Damage Assessment and Repair) Field Trials Held at Meppen, Germany, from 27 June to 14 July 1988, (Aberdeen Proving Ground, MD, 1989), p. 2; U.S. Army Tank and Automotive Command, FY88 Meppen Joint Battlefield Assessment and Repair (BDAR) Live Fire Trials 27 June - 13 July 1988, (Warren, MI, 1989), p. 1.

45. Berkowitz, David; Unruh, Kenneth D.; and Kruse, Loren, Results of the 1987 BDAR (Battle Damage Assessment and Repair) Field Trials Held in Meppen, Federal Republic of Germany, from 7 - 30 July 1987, (Aberdeen Proving Ground, MD, 1988), p. xii.

46. Berkowitz, et. al., Results of the 1987 BDAR (Battle Damage Assessment and Repair) Field Trials Held in Meppen, Federal Republic of Germany, from 7 - 30 July 1987, p. xi; Berkowitz and Kruse, Results of the International BDAR (Battle Damage Assessment and Repair) Field Trials Held at Meppen, Germany, from 27 June to 14 July 1988, p. 2.

47. TRADOC BDAR Office, Fact Sheet, 20 Feb 92, p. 1.

48. U.S. Army Aviation School, Director of Combat Developments, ATSQ-LCD-M, Fact Sheet, Subject: Battle Damage Assessment and Repair (BDAR), (Fort Eustis, VA, 1 Dec 91).

49. JULLS DSSN 17 0153.

50. "Battle Damage Repair Kits Available," Army Logistician (March-April 1992), p. 42.

51. Reference units not having BDR kits: JULLS DSST 123 3977, addresses aviation BDR kits; JULLS DSSN 113 4195, addresses M1 BDR kits; JULLS DSST 8 6556, addresses ground equipment in general.

52. JULLS DSSN 13 0951. An interesting side note, the author recalls that the hydraulic and machine shop capability in the forward maintenance company was removed during the 1986 reorganization of the DISCOM under the Army of Excellence (J-series TOE). This action occurred in spite of the field comments from maintenance units that the fabrication capability was critical to combat repair.

53. JULLS DSSN 173 0234.

54. TRADOC BDAR Office, Fact Sheet, 20 Feb 92.

55. JULLS DSST 123 3977.

56. The February 1992 Fact Sheet from the TRADOC BDAR Office, refers to NCO training only. During phone conversations with this office, the author was led to believe that to increase BDAR training at this level would require removal of other instructional material. This trade-off is very difficult and not extremely likely in the near future. At the Ordnance Center and School, some in-roads have been made, however, as the emphasis on those skills within the current curricula which support BDAR techniques have been increased.

57. Mueller-Hillerbrand, Burkhart, German Tank Maintenance in World War II, (Washington, D.C., 1982), p. 2.

58. Ibid., p. 2.

59. Ibid., p. 25.

60. Ibid., p. 35.

61. Ibid., pp. 30-31.

62. U.S. Army Tank and Automotive Command, FY88 Meppen Joint Battlefield Assessment and Repair (BDAR) Live Fire Trials 27 June - 13 July 1988, p. 4.

63. Liden, Lars T., "U.S., German armies compare BDAR," Ordnance Magazine, (May 1991), p. 28.

64. Donnelly, C. N., et. al., The Sustainability of the Soviet Army in Battle, (Sandhurst, UK, 1986), Book 7, pp. 272, 273.

65. Ibid., p. 283.

66. Ibid., p. 277.

67. Srull, Donald W., et.al., Battle Damage Repair of Tactical Weapons Systems: An Assessment, p. 2.

68. Herzog, Chaim, The War of Atonement, October 1973, (Boston, 1975), pp. 108, 113.

69. Adan, Avraham, On the Banks of the Suez, (San Francisco, 1980), p. 442.

70. Ibid., p. 203.

71. Srull, Donald W., et.al., Battle Damage Repair of Tactical Weapons Systems: An Assessment, p. 2.

72. Liden, "U.S., German armies compare BDAR," p. 28.

73. U.S. Army, Training and Doctrine Command/Army Materiel Command Pamphlet Pam 70-11, RAM Rational Report Handbook, (Fort Monroe & Alexandria, VA, 1 Feb 85), p. B-1.

74. U.S. Army, AR 750-1, p. 9.

75. U.S. Army, TM 9-2350-255-BD, p. 10-66.

76. Berkowitz, et. al., Results of the 1987 BDAR (Battle Damage Assessment and Repair) Field Trials Held in Meppen, Federal Republic of Germany, from 7 - 30 July 1987, p. 18.

77. Replacement time estimate provided by Armor Battalion Motor Sergeant, 1st Infantry Division, phone conversation with author, 18 Nov 92; BDAR reference is from TM 9-2350-255-BD, Dec 83, with Ch 1, May 85, p. 10-55; MPL reference, DA Pam 710-2-117, p. 590.

78. DA Pam 710-2-117, MPL for LIN T13374, Tank, Combat FT 105mm gun (Abrams) M1, p. 588-591; Army Master Data File, April 1992.

79. Srull, et. al., Battle Damage Repair of Tactical Weapons: An Assessment, p. 10. While seemingly simple, the M1's wiring harnesses are not marked for easy match up during splicing. The difference in the time required to repair a wiring harness with and without such markings is dramatic: for a 100 wire harness, Srull, et. al. estimate repair time to be 4 hours if the wires are marked, 19-23 hours for an unmarked harness.

80. U.S. Army, AR 750-1, p. 9.

81. Srull, et. al., Battle Damage Repair of Tactical Weapons: An Assessment, pp. x, B-10, B-13.

82. Srull, et. al., Battle Damage Repair of Tactical Weapons: An Assessment, pp. x, 21.

83. Rockwell, Christopher, The Imperatives of Tactical Level Maintenance (Fort Leavenworth, 1986), p. 8. Rockwell credits mobile tank assembly repair plants with providing a "significant improvement" to Soviet maintenance capability in World War II.

84. Koivu, Albert H. and Saczalski, Kenneth, Feasibility Study for Field Remanufacture of Failed Army Vehicle Parts, (Costa Mesa, CA, 1988). This study recommends siting remanufacture capability forward using transportable machinists equipment and "novel material," p. 28. It further recommends that the focus for such capability be those critical components which are most difficult to obtain through the supply system and which don't have a BDAR fix, p. 43.

85. TRADOC BDAR Office, Fact Sheet, 20 Feb 92; TRADOC BDAR Office fact sheet; JULLS DSSN 13 0951.

86. Marshall, S.L.A., The Soldiers Load, The Mobility of a Nation, (Quantico, VA, 1980), pp. 80-84.

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